MORRISON KNUDSEN/K-V ASSOCIATES
C-SPARGE

MORRISON KNUDSEN CORPORATION

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December 14, 1999

Mr. Michael Hightower
Sandia National laboratories
P.O. Box 5800
Albuquerque, NM 87195-0755

RE: Summary of Estimated Costs for Ozone Sparging Using the C-Sparge Process
Paducah ITRD Project~ Paducah, KY

Dear Mike:

Attached is a table summarizing the estimated costs for installation and operation of ozone sparging using the C-Sparge Process at the U. S, Department of Energy Paducah Gaseous Diffusion Plant, Paducah, Kentucky. The attached table is arranged in general conformance with your requested format.

Cost scenarios

As requested we have developed costs for seven different site condition scenarios. These scenarios are as follows:

1) Treatment of saturated soil in the Upper Continental Recharge System (UCRS). Treatment volume equals 10,000 cubic yards (yd^3). Trichloroethylene (TCE) is the only contaminant and is present at a concentration of greater than 100 parts per million (ppm).

   System Design
   C-Sparge wall mounted unit with 2 groundwater recirculation sparge wells.

2) Treatment of non-saturated soil in the UCRS. Treatment volume equals 10,000 yd^3 TCE is the only contaminant and is present at concentration of greater than 100 ppm.

   System Design
   High vacuum extraction with C-Sparge wall mounted unit. Design includes 4 vapor extraction wells and 6 ozone injection sparge points. Ozone is mixed with TCE in the soil and the combined mixture is oxidized under vacuum extraction The extracted soil

gas contains TCE levels acceptable for discharge to the atmosphere. Carbon adsorption costs are included in the estimate as a contingency.

3) Treatment of soil near the C-400 Building, Treatment volume equals 40,000 yd. TCE is the only contaminant and *is present* at a concentration of greater than 1,000 ppm.

System Design - High vacuum extraction, with C-Sparge palletized unit *in a protected* enclosure. Design includes 3 vapor extraction wells and 5 ozone injection sparge points for treatment of the unsaturated *zone* and 4 recirculation wells for treatment of saturated materials. Ozone Is mixed with TCE in the soil and the combined mixture is oxidized under vacuum extinction. The extracted soil gas contains TCE levels acceptable *for discharge to* the atmosphere. Carbon adsorption costs are included in the estimate as a contingency.

4) Treatment of additional soil near the C-400 Building. Treatment volume equals 10,000 yd^3. TCE is the only contaminant and is present at a concentration of greater than 10,000 PPM.

System-Design
Perozone (combination of peroxide and ozone treatment) injection for addressing and treating possible DNAPL's. C-Sparge trailer unit equipped with ozone generator capable of producing 1,500 grams ozone per day. Hydrogen peroxide and ozone are fed simultaneously into special spargepoints® which are placed at shallow and deeper depths in the aquifer. Design includes 1.2 spargepoints® placed at 20 foot spacings within the treatment area. During treatment temperature will be monitored.

5) Treatment of groundwater within the Regional Gravel Aquifer (RGA) near the contaminant source. Treatment volume equals 50,000 yd^3. TCE and Technetium. (Tc-99) are the only contaminants present. The TCE concentration is greater than 1,000 parts per billion (ppb) and the Tc-99 concentration ranges from 100 to 1,000 pico Curies per liter (pCi/L).

System Design
C-Sparge 4-well palletized unit in an enclosure and 4 groundwater recirculation sparge wells. Recirculation wells are equipped with ion exchange cartridges for Tc-99 removal. Design is based on an 85-foot radius of influence (170 foot zone of capture). Well spacing includes 30% overlap as a factor of safety.

6) Treatment of additional groundwater within the RGA near the source. Treatment volume equals 5,000 yd^3. TCE and Tc-99 are the only contaminants present. The TCE concentration is greater than 100,000 ppb and the Tc-99 concentration ranges from 100 to 1,000 pCi/L.

System Design:
Perozone (combination of peroxide and ozone treatment) injection for addressing and treating possible DNAPL's. C-Sparge trailer unit equipped with ozone generator capable of producing 1,500 grams ozone per day. Hydrogen peroxide and oxone are fed simultaneously into special spargepoints® which are placed at shallow and deeper depths in the aquifer. Design includes 10 spargepoints® placed at 15 foot spacings and 2 recirculation wells within the treatment area. Recirculation wells are equipped with ion exchange cartridges for Tc-99 removal

7) Treatment of groundwater within the RGA downgradient of the source. The treatment scheme will involve placing sparge welts in a linear arrangement to contain the plume The containment wall (interceptor fence) is 4,000 feet long. The TCE concentration is less than 1,000 ppb and the Tc-99 concentration ranges from 100 To 1,000 pCi/L

System Design:
Three C-Sparge 10-well palletized units in an enclosure and 30 groundwater recirculation sparge wells. Recirculation wells are equipped with ion exchange cartridges for Tc-99 removal. Design is based on an 85-foot radius of influence (170 foot zone of capture). Well spacing includes 30% overlap as a factor of safety.

Should you have any questions regarding this letter or the attached table, please do not hesitate to call me at (216) 523-5286 or Bill Kerfoot at (508) 539-3002.

Sincerely yours,

Bruce B. Ehleringer
Hydrogeologist / Program Manager

CC: William Kerfoot, President K-V Associates

attachments

Cost Item	UCRS		C-400			RGA	
	Saturated 10,000 yd^3 100 ppm	Non-Saturated 10,000 yd^3 100 ppm	40,000 yd^3 1,000 ppm	10,000 yd^3 1,000 ppm	50,000 yd^3 1,000 ppb	5,000 yd^3 100,000 ppb	4,000 LF 1,000 ppb
Capital Costs							
Number of Wells	2 Wells	1 Wells	12 Wells	12 Wells	4 Wells	12 Wells	30 Wells
Engineering and Design	$10,000	$10,000	$15,000	$10,000	$15,000	$10,000	$20,000
Permits / KVA Licensing Fee	$$2,600	$1,500	$6,600	$4,800	$8,400	$4,800	$42,000
Mobilization	$5,000	$5,000	$8,000	$5,000	$8,000	$8.000	$14.000
System Cost	$34,500	$41.500	$82,000	$99,300	$82,000	$99,300	$410,000
Drilling and Well Construction	$20.500	$35,000	$70.000	$70,O00	$80,000	$70,000	$300,000
Utility Connections (Electrical Hookup	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
System Installation	$10.000	$10.000	$25,000	$10.000	$10.000	$10.000	$45,000
Demobilization	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000	$5,000
Estimated Total Capital Costs	$92,600	$113,000	216,500	$209,100	$193,400	$212,100	$851.000 $213/Lin. Ft
Cost per Yd^3	$9.26	$11.30	$5.41	$20.91	$3.87	$42.42	$1.44
Operation and Maintenance Coals							
System Operation Manpower	$20,000	$20,000	$,35,000	$50,000	$20.000	$20,000	$100,000
Energy and Utilities	$6,000	$8,000	$12,000	S8,000	$7.000	$8,000	$35,000
Process Materials and Consumables (on Exchange Resin)	NA	NA	NA	NA	$8,000	$2,000	$30,000
Treatment Process Monitoring arid Reporting	$8,000	$8,000	$25,000	$15,000	$10,000	$15,000	$50,000
Waste Treatment Storage, Disposal	$2,500	$6.500	$10,000	$8,000	$8,000	$8,000	$40,000
Hardware or Equipment Replacement	$2,000	$2,000	$6.000	$8000	$6,000	$6,000	$30,000
Estimated Annual 0 & M Costs	$37,500	$44,500	$88,000	$87,000	$57,000	$59,000	$285,000
Performance							
Expected Treatment Period	1 Year	1 Year	2 Year	2 Year	2 Year	1 Year	30 Year
Estimated Amount of Contaminant Reduction							
TCE	99.5%	95%	95%	95%	>99.5%	95%	>99.5%
Tc-99	NA	NA	NA	NA	>97%	>97%	>97.0%
Estimated Level of Residual Contaminant							
TCE	0.1 ppm	5 ppm	5 ppm	<500 ppm	<5 ppb	<5 ppb	<5ppb
Tc-99	NA	NA	NA	NA	<30 pCi/L	<30 pCi/L	<30pCi/L
Wastes Generated							
TCE (Carbon)	0	4 Drums	10 Drums	0	0	0	0
Tc-99 (Ion Exchange Resin)	NA	NA	NA	NA	4 ft^3/year/well	4 ft^3/year/well	4 ft^3/year/well

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FAX COVER SHEET

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From: Bruce Ehleringer

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Phone No.: 216-523-5286

Subject: Proposal for Ozone Sparging Demonstration Using the KVA C-Sparge Process at the PGDP, Paducah, Kentucky

Message

Mike-

Attached is a fax copy of the demonstration proposal that KVA and NM have jointly prepared. Section 6 presents the one page write-up pertaining to "budgetary unit costs" for ozone sparging that we discussed yesterday.

This proposal is incomplete in that it does not include costs for the demonstration (Section 6) or schedule (Section 7). I am still awaiting some cost information.

If you could review this document and provide comments (expansions and/or deletions) I would appreciate it. In the mean time, I will continue to work on the cost estimate.

Thank you,

Bruce

million hours without a lost time accident. Two other MK projects surpassed 1,000,000 hours without a lost time accident during 1999: the Rocky Mountain Arsenal and the ALCOA Massena projects.

1.1 C-Sparge Process

The C-Sparge® process involves micro-sparging with an ozone/air mixture to remove dissolved VOCs in groundwater. The extracted VOCs then react with the encapsulated ozone in a gas/gas reaction described by the crigee mechanism (the "C" in C-Sparge). Halogenated VOCs decompose to a short-lived (milliseconds) intermediate (carboxyl oxide) which reacts with water (hydrolyzes) as it exits the bubble to yield reaction end products Cl, H_20, and $C0_2$. With aromatic VOCs, the decomposition products are H_20, and $C0_2$. This is a very clean reaction sequence since the VOC is concentrated in the fine bubbles and reacts with the ozone on a mole to mole basis. The concentration of ozone in the bubbles is matched to the expected VOC concentration and field checked by "bubble traps".

The reaction for decomposition of trichloroethylene (TCE) is presented as.

$$H_20 + HC_2CI_3 + 0_3 \sim \ 2CO_2 + 3HC\ I$$

Assuming an ozone injection rate of 200 grams per day (4.17 moles/day) yields the following:

$$4.17\ \mathit{mol/day}\ H_20 + 4.17\ \mathit{mol/day}\ HC_2CI_3 + 4.17\ \mathit{mol/day}\ 0_3 =$$
$$8.34\ \mathit{mo/lday}\ C0_2 + 12.51\ \mathit{mol/day}\ HCl$$

and that:

$$12.51\ \mathit{mol/day}\ HCl + 12.51\ \mathit{mol/day}\ HCO_3,$$
$$12.51\ \mathit{mol/day}\ H_20 + 12.51\ \mathit{mol/day}\ C0_2 + 12.51\ \mathit{mol/day}\ Ct$$

To determine the amount of HCO_3, which may be consumed it is necessary to know the groundwater pH and the bicarbonate alkalinity.

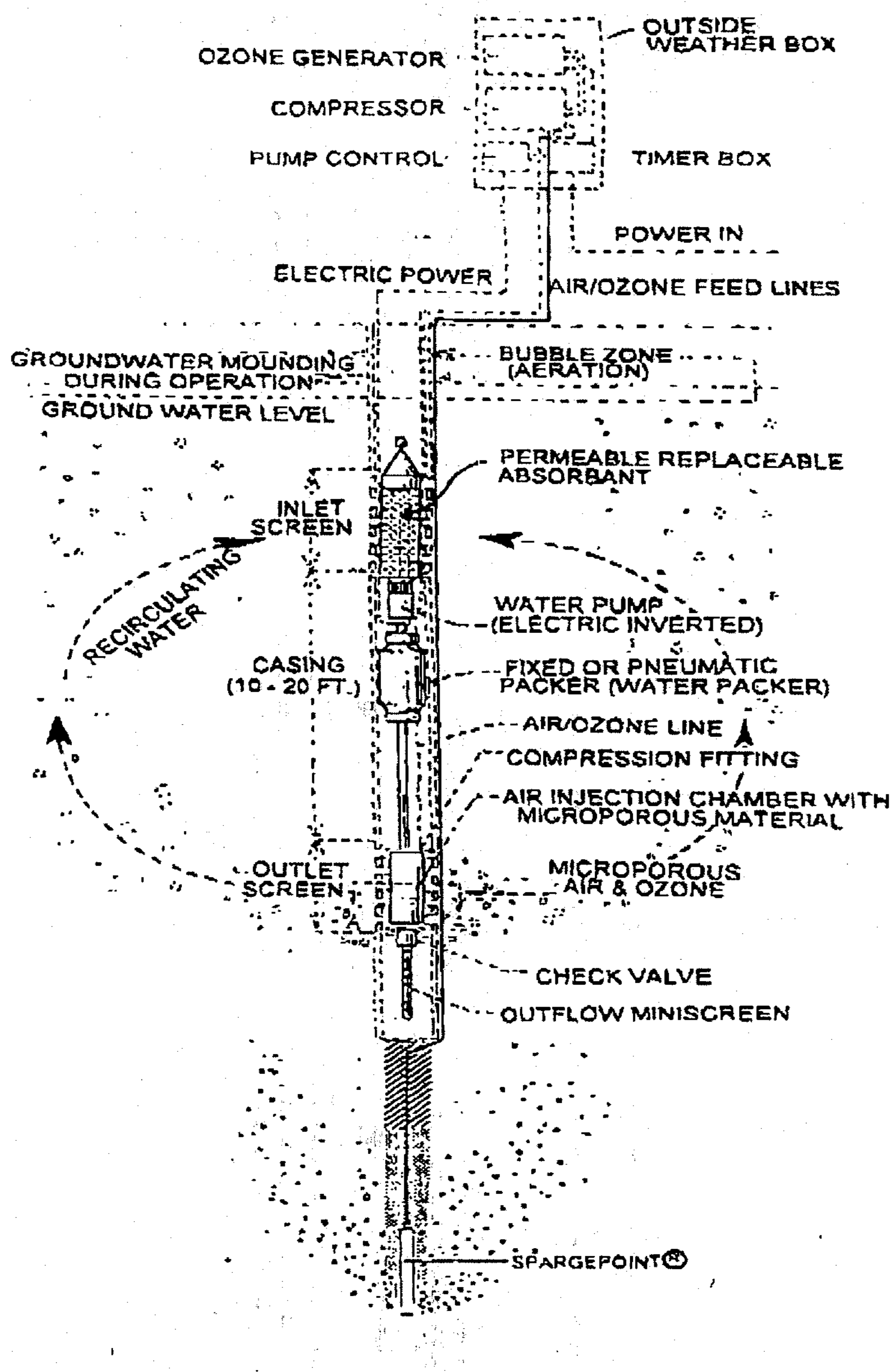
The C-Sparge-Process® process focuses ozone reaction selectively to air strippable compounds which invade the bubbles. As a result, if the encapsulated ozone concentration is maintained at a low multiplier of the strippable VOCs, then no ozone is available for side reactions with other dissolved organic compounds which have low Henry's numbers. Primary reactions do not create toxic by-products because the reactions proceed so rapidly and bubble rise times are quite long. As of yet, the only identified end products have been chloride and carbon dioxide. Dissolved oxygen concentrations can also be expected to increase.

One possible concern with ozone sparging is the incomplete oxidation of VOCS and transfer of the stripped VOCs to the unsaturated zone. This is not an issue if the ozone concentration is matched to the groundwater VOC concentration. Depending on regulatory requirements, a vapor control unit within the well may be required during pilot testing or during initial system startup to demonstrate that this situation is not occurring.

The C-Sparge system is designed to efficiently remove VOCs from groundwater and to maximize the radius of influence of the sparge wells. The sparge well design includes placement of a spargepoint® below the well casing and the construction of a 4- or 6-inch diameter well with two screened intervals. The purpose of the two screened intervals is to allow groundwater extraction and re-injection to occur in the same well, thus creating a recirculation flow cell that increases the well radius of influence. An in-well unit consisting of a spargepoint, packer, and groundwater pump is placed within each well. Groundwater is extracted from the upper screened interval, and re-injected in the lower screen. The lower screen interval is also used for sparging. Groundwater extraction/injection and sparging from the two spargepoints® in each sparge well is cycled (pulsed) and each well is operated sequentially to allow greater ozone spreading outward from the well, mixing of the water column to reduce stratification, and increased ozone contact time, thus facilitating more complete VOC removal. Figure I is a drawing showing the C-Sparge® dual well screen design; placement of the spargepoints®, groundwater pump, and replaceable adsorbent (ion exchange resin); the movement of micro-fine bubbles; and groundwater flow in the vicinity of the C-Sparge® wells.

The spargepoints® have openings that vary in size from 20 to 40 microns (0.0008 to 0.002 inch) and generate microfine bubbles that move laterally outward from the sparge well into the aquifer. The bubbles generated are five to 12 times smaller that those generated through conventional sparging using a 0.010-inch slotted well screen and are small enough that they will move through the aquifer intergranular spaces. By combining groundwater re-injection and sparging, lateral movement of bubbles from the sparge well into the formation is substantially greater than with a conventional sparge well and short-circuiting near the well is not an issue.

Results with the C-Sparge® system show that 3-dimensional flow of microfine bubbles increases over time and results in a large effective treatment area. The recirculating bubble cloud treats both dissolved VOCs in groundwater and removes VOCs that may be adsorbed onto the soil matrix. Velocity changes created by the cycling of ozone sparging and


OUTSIDE WEATHER BOX
OZONE GENERATOR
COMPRESSOR
PUMP CONTROL
TIMER BOX
POWER IN
ELECTRIC POWER
AIR/OZONE FEED LINES
GROUNDWATER MOUNDING DURING OPERATION
BUBBLE ZONE (AERATION)
GROUND WATER LEVEL
PERMEABLE REPLACEABLE ABSORBANT
INLET SCREEN
RECIRCULATING WATER
WATER PUMP (ELECTRIC INVERTED)
CASING (10 - 20 FT.)
FIXED OR PNEUMATIC PACKER (WATER PACKER)
AIR/OZONE LINE
COMPRESSION FITTING
AIR INJECTION CHAMBER WITH MICROPOROUS MATERIAL
OUTLET SCREEN
MICROPOROUS AIR & OZONE
CHECK VALVE
OUTFLOW MINISCREEN
SPARGEPOINT®

groundwater extraction/injection within each sparge well and the sequencing of the individual sparge wells increases groundwater circulation. The re-circulation zone created for each sparge well allows multiple treatment passes through the sparge well and ozone bubble cloud before groundwater exits the area of sparge well influence.

C-Sparge® master control units are designed to control one to 10 sparge wells. Electrical power requirement are single-phase 110 volt. The master control units allow sparging with an ozone/air mixture; increased oxygen/air mixture; or air. Depending on the thickness of the saturated water interval or the remedial strategy, the C-Sparge® master control unit can be used for conventional sparging without groundwater extraction/injection and the creation of a groundwater recirculation cell. Ozone sparging using this mode of operation is effective for treatment of VOCs present in perched water, thin water-bearing intervals, and saturated soil in the capillary fringe.

Implementation of the C-Sparge® ozone injection requires performance of a pilot test to obtain optimal operational parameters and to determine the radius of influence of the sparge wells, Pilot testing generally involves the construction of one or two sparge wells and monitoring of three or more monitoring wells positioned at distances ranging from 20 to 80 feet from the sparge wells. Pilot testing is generally performed in areas where 1) existing monitoring wells are present to reduce monitoring well construction cost and to take advantage of historical water quality data, or 2) in the area where the planned sparge wells are to be located so diat the sparge wells can be used in the long-term remedial design.

Prior to pilot testing baseline groundwater samples are collected and analyzed from each well to be used in the pilot study and the depth to water measured. Groundwater flow direction is also determined in each sparge and monitoring well using a KVA groundwater flow meter. Groundwater flow direction determined by the flow meter may differ from that determined using groundwater elevation data and is useful for evaluating aquifer heterogeneity and preferred flow paths.

Pilot study testing involves the performance of a step pressure test and a steady pressure test of each sparge well. After completion of individual well testing and determination of optimal operation parameters, the sparge wells are continuously operated for a three to 14 day period. The testing duration is based on site specific issues: aquifer thickness, aquifer heterogeneity, groundwater velocity, VOC stratification within the aquifer, etc. This longer term test is to evaluate site specific conditions that may impact system performance and to obtain additional groundwater VOC field screening and analytical data. The VOC data provides a preliminary indication of the VOC oxidation rate and information on VOC stratification that may be present within the aquifer.

7.0 UNIT COST BUDGETARY ESTIMATE FOR IMPLEMENTATION OF OZONE SPARGING WITH THE C-SPARGEO SYSTEM

A unit cost on the order of $16 per cubic yard is estimated if the C-Sparge® process is implemented for in-situ groundwater oxidation of VOCs and removal of Tc-99 using an in-well ion exchange resin cartridge. This unit cost estimate is based on a sparge well radius of influence of 50 feet and a saturated aquifer thickness of 30 feet, which equates to a treatment volume of roughly 8,700 cubic yards. The demonstration test is designed to evaluate a radius of influence of up to 80 feet and this unit cost estimate can be expected to decrease based on the actual radius of influence.

Our experience indicates that mobilization of a trailer system to treat only VOCs in groundwater would cost about $75,000, or about $ 8.60 per cubic yard of saturated aquifer material (cost includes equipment, installation, startup, and sparge well drilling cost). With Tc-99 removal and normal DOE decontamination procedures, disposal of spent ion exchange resin, the unit cost will increase but most-likely not above $16 per cubic yard.

The above unit cost estimate does not include operation and maintenance (O&M), compliance monitoring, administrative support, or preparation of design documents and reports. These additional costs are scale dependent, and are higher if distributed over a small treatment volume site versus a large treatment volume site.

Table 1.1a
Preliminary Engineering Cost Estimate for C-400 Source(B400-200) Area
Pneumatic Fracturing Enhanced Soil Vapor Extraction
Paducah ITRD Project
Paducah, Kentucky

ITEMS	QUANTITY	MT	UNIT COST	TOTAL COST
ANNUAL OPERATION AND MAINTENANCE (O & M COSTS)				
(For Year I) -.				
	Subtotal			**$45,000**
Contingency (25%)				$11,000
TOTAL ANNUAL O&M COST				$56,000
(For Year 2):				
	Subtotal			$44,000
Contingency (25 %)				$11,000
TOTAL ANNUAL O&M COST				$55,000
(For Year 3),				
	Subtotal			$43,000
Contingency (25%)				$11,000
TOTAL ANNUAL O&M COST				$54,000